

# **Determination of the Spatial Variation of the Atmosphere and Ocean Wave Fields in Extremely Light Wind Regimes**

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## **LONG-TERM GOALS**

Existing parameterizations of heat, moisture, and momentum fluxes in the marine atmospheric boundary layer (MABL) perform poorly under weak wind regimes, especially in regions of inhomogeneity. These problems are due to a variety of processes. In order to address these various forcing mechanisms, high-resolution, high-fidelity atmospheric and surface wave data are needed to describe energy exchange across the air-sea interface. The overall long-term goal of the Coupled Boundary Layers Air-Sea Transfer (CBLAST) low-wind initiative is to acquire these data in order to better understand air-sea interaction in extremely light wind regimes.

## **OBJECTIVES**

The objective is to advance our understanding of the processes that control the exchange of heat, moisture, and momentum across the air-sea interface. More specifically, we will measure vertical fluxes of momentum and heat in the MABL and in the ocean surface layer and to identify the processes that influence these fluxes. We will work with other CBLAST-Low investigators to close budgets for heat and momentum, test flux parameterizations, and obtain other measurements sufficient to provide boundary conditions for a large eddy simulation or local application of a regional-scale simulation.

## **APPROACH**

The LongEZ (registration N3R) research aircraft has been used extensively to acquire data for a variety of air quality and environmental research projects (Fig.1). Because of its clean aerodynamics

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and advanced instrument systems, this aircraft has proven to be especially powerful in studying the MABL and air-sea exchange processes. The instrument suite and data acquisition system are used to measure mean properties of the atmosphere as well as turbulent fluxes of heat, moisture, and momentum. Remote sensors are used to characterize ocean wave properties. Data acquired by N3R will support the test and refinement of parameterizations used in air-sea models. These measurements will provide important boundary conditions to determine the processes controlling the exchange of energy across the air-sea interface.



**Fig. 1. LongEZ N3R in Martha's Vineyard during the CBLAST-Low 2001 pilot study.**

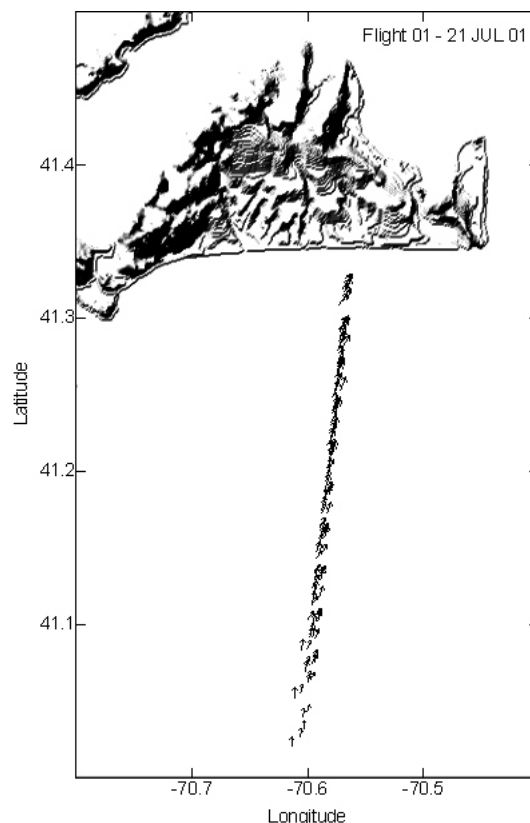
Various *in situ* and remote sensors are employed by N3R for the measurement of atmospheric and wave field properties. The “best” aircraft turbulence (BAT) probe is used to acquire high-frequency wind, temperature, and pressure. An open-path infrared gas analyzer measures turbulent fluctuations in water vapor. Upward and downward radiometers are also employed to acquire short and long wave radiation. Global positioning system (GPS) technology provides precise position, velocity, attitude, and time. A laser altimeter array and a Ka-band scatterometer are used to determine long and short wave characteristics, respectively, of the sea surface. The lasers are used to measure wave height and directional wave spectra for wavelengths greater than 3 m. The scatterometer is used to estimate the integrated surface roughness of short-scale waves by measuring the intensity of quasi-specular backscatter. The backscatter signal strength is related to the mean-square-slope of the sea surface for wavelengths from 1 to 100 cm.

## WORK COMPLETED

N3R was deployed to Hyannis, Massachusetts in late July 2002 to conduct the second CBLAST-Low field study which was to be conducted over a four-week period over the waters south of Martha's Vineyard. The first mission was flown on 2 August 2002 and lasted about three hours. Dr. Timothy L. Crawford, co-PI and N3R pilot, departed at 1155 EDT on 3 August 2002 for the second CBLAST-Low research flight. At 1505 EDT, N3R was spotted in the water several miles south of Martha's Vineyard. The State of Massachusetts Medical Examiner determined that Dr. Crawford suffered a fatal cerebral hemorrhage (stroke) while piloting the N3R during the research flight which precipitated its crash into the ocean. N3R and all of its instruments was destroyed. The N3R component of the CBLAST-Low field study was immediately terminated.

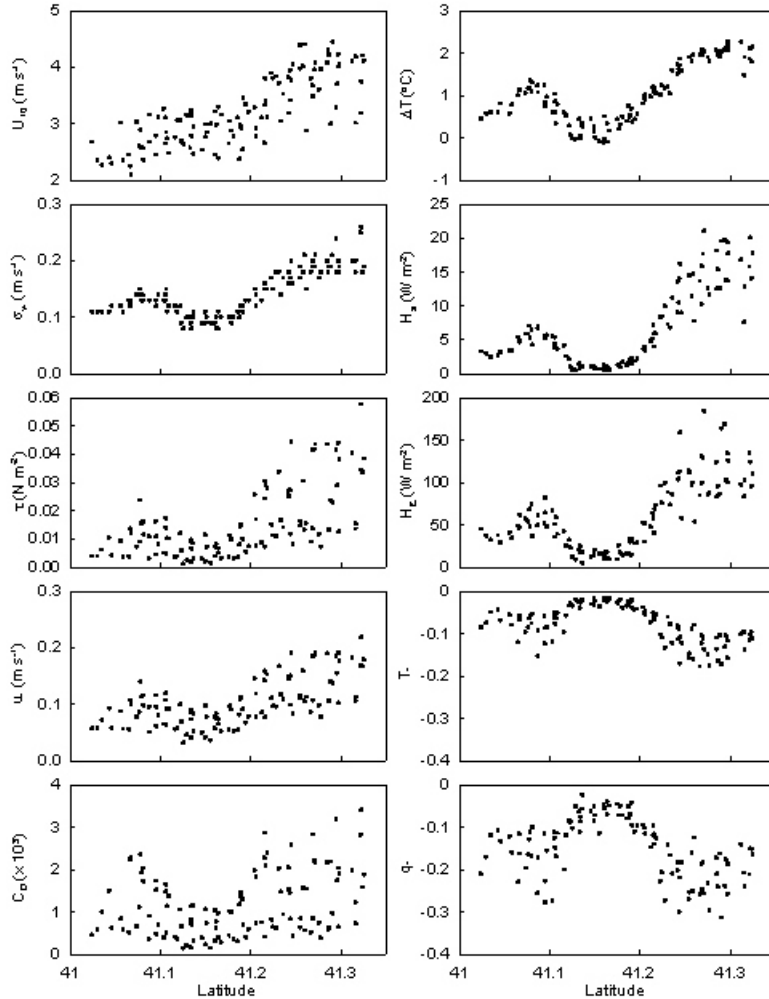
## RESULTS

Data analysis continues on CBLAST-Low data acquired by N3R during the 2001 pilot study. On 21 July 2001 between



**Fig. 2. Mean wind vectors from CBLAST-Low Flight 01 (21 JUL 01).**

1300 and 1630 UTC (Flight 01), N3R flew twelve north-south flux legs 10 m above the ocean surface from near the southern shoreline of Martha's Vineyard out into the Atlantic Ocean for a distance of about 30 km. Fig. 2 shows 60-s (~3 km) mean wind vectors from Flight 01. Winds were about  $2 \text{ m s}^{-1}$  from the south-southwest at the southern end of the flux legs and increased linearly to about  $4.5 \text{ m s}^{-1}$  from the southwest near the coastline. Various mean and turbulence parameters are shown in Fig. 3. These include the 10-m mean wind speed ( $U_{10}$ ), air-sea temperature difference ( $\Delta T$ ), standard deviation of the vertical wind speed ( $\sigma_w$ ), wind stress ( $\tau$ ), friction velocity ( $u_*$ ), drag coefficient ( $C_D$ ), sensible heat flux ( $H_S$ ), latent heat flux ( $H_E$ ), and temperature and humidity scaling parameters ( $T_*$  and  $q_*$ , respectively).

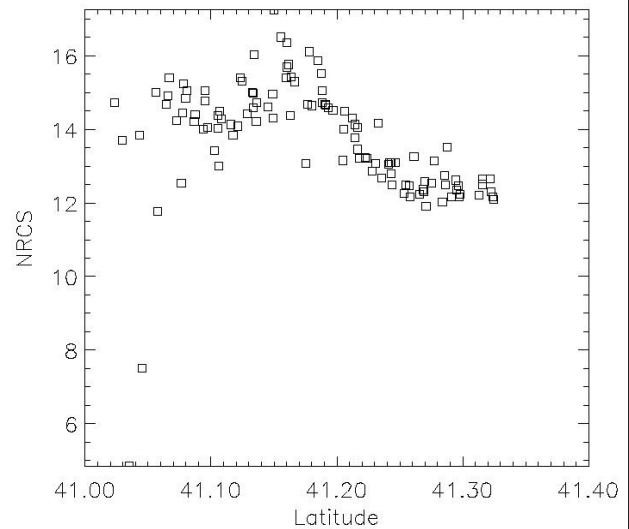


**Fig. 3. Flight 01 turbulence parameters. Left column: 10-m wind speed  $U_{10}$ , standard deviation of vertical wind speed  $\sigma_w$ , wind stress  $\tau$ , friction velocity  $u_*$ , and drag coefficient  $C_D$ . Right column: Air-sea temperature difference  $\Delta T$ , sensible heat flux  $H_S$ , latent heat flux  $H_E$ , temperature  $T_*$  and humidity  $q_*$  scaling parameter.**

The air-sea temperature difference  $\Delta T$  increases from  $0.5$  to  $1.5$   $^{\circ}\text{C}$  over the first 5 km at the southern end of the flux legs with a local maxima about 25 km from the shoreline. Note a positive  $\Delta T$  represents colder air over warmer water, i.e., an unstable atmospheric boundary layer. Over the next 8 km,  $\Delta T$  decreases to about  $0$   $^{\circ}\text{C}$ , representing a local minima about 17 km from the shoreline.  $\Delta T$  increases from  $0$   $^{\circ}\text{C}$  to slightly over  $2$   $^{\circ}\text{C}$  from 17 km offshore to the coastline. Most of the turbulence parameters display a high correlation ( $> 0.9$ ) to  $\Delta T$ . From a mechanically mixed perspective, vertical mixing ( $\sigma_w$ ) is proportional to  $\Delta T$ . The wind stress  $\tau$  is also highly correlated (0.70) to  $\Delta T$  but shows considerably more scatter near the shoreline. This is probably due to shoaling of waves in shallower waters. As expected, the friction velocity  $u_*$  is very similar to  $\tau$ . The drag coefficient  $C_D$  shows considerable scatter both at the southern and northern ends of the flux legs where the boundary layer is unstable. Conversely, much less scatter is observed over the waters where  $\Delta T$  approaches  $0$   $^{\circ}\text{C}$ . From a buoyantly mixed perspective, the fluxes of sensible and latent heat ( $H_S$  and  $H_E$ , respectively) are highly correlated (0.94 and 0.88, respectively) to

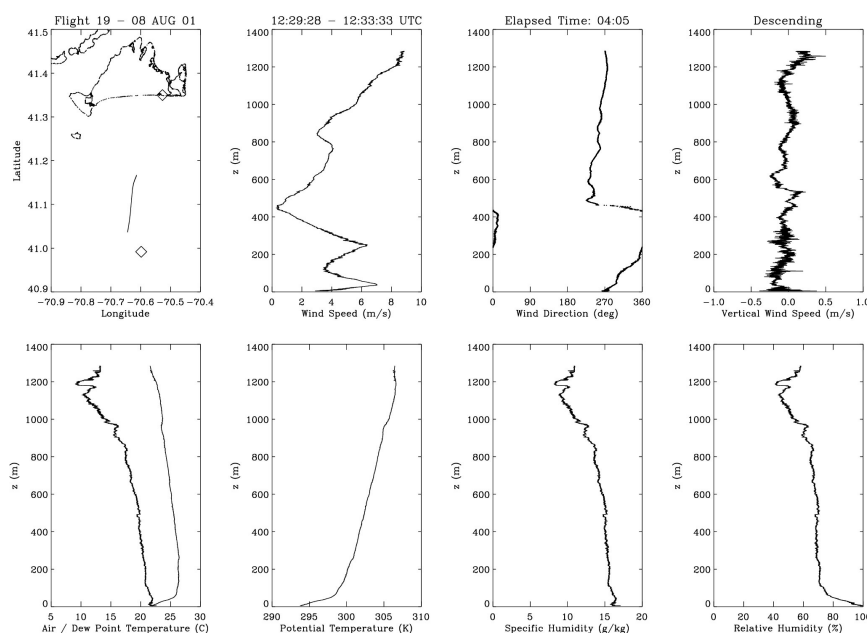
$\Delta T$ . As expected, the latent heat flux is an order of magnitude larger than the sensible heat flux. The temperature and humidity scaling parameters ( $T_*$  and  $q_*$ , respectively) are nearly zero over the waters

where  $\Delta T$  approaches  $0^\circ\text{C}$  and become largely negative over the waters where unstable conditions exist. Fig. 4 is a plot of the normalized radar cross section (NRCS) which is an inverse measure of the ocean's surface roughness. NRCS exhibits an inverse correlation with  $\Delta T$ . As the surface of the ocean becomes more smooth ( $\Delta T \sim 0^\circ$ ), NRCS increases. Closer to the shore, NRCS decreases as the surface roughness increases probably due to shoaling. The increase in scatter farthest from shore is likely due to the low wind speeds and hence lower surface roughness. At the lower wind speeds, the scatterometer has more difficulty registering returns from the ocean surface as there are not as many facets normal to the radar beam.



**Fig. 4. Normalized radar cross section (NRCS) for Flight 01.**

Fig. 5 shows an example sounding acquired by N3R on 8 August 2001 in the early morning just north of the WHOI ASIMET buoy. The weather was hazy, very hot, and humid in Martha's Vineyard with very light northwesterly winds observed at the airport ahead of a stalled cold front. The 10-m surface winds are light ( $3\text{ m s}^{-1}$ ) from the west. However, a pronounced  $7\text{ m s}^{-1}$  jet from the west-northwest is found a mere 50 m above the ocean surface. The air temperature profile shows a very strong inversion of  $5^\circ\text{C}$  over that vertical distance of 50 m. The relative humidity in this layer quickly decreases from saturation to about 80%.



**Fig. 5. MABL profiles of wind, temperature, and humidity during Flight 19 (08 AUG 01).**

The winds continue to veer to the northwest with height from 50 to 100 m; however, the wind speed decreases to slightly less than  $4\text{ m s}^{-1}$ . The air temperature and humidity are nearly isothermal in this overriding layer. The winds continue to veer with height to the north from 100 to 250 m with wind speeds once again increasing to a maximum jet of  $6\text{ m s}^{-1}$ . Potential temperature profile still shows a very stable layer while humidity decreases very slowly with height.

From 250 to 450 m, the winds abruptly back from the north to

southwest with winds steadily decreasing from 6 to less than 1 m s<sup>-1</sup>. While the air temperature and specific humidity slowly decrease with height, the relative humidity is fairly constant. From 450 to 1300 m, the wind speed increases linearly with height from near calm to 9 m s<sup>-1</sup> while the wind direction veers slightly from southwesterly to westerly. The specific humidity falls to a minimum of 10 g kg<sup>-1</sup>.

The moist, southwesterly synoptic-scale flow of the Bermuda High is apparent above 450 m. Meanwhile, the offshore flow in the lowest 200 m of the MABL resembles a land breeze flow moving off the slightly cooler land mass over the warmer waters. A common feature seen in other N3R profiles under very stable conditions is the low-level jet found near the top of these strong surface-based inversions.

## **IMPACT/APPLICATIONS**

The data acquired by N3R will have a direct impact on our understanding of energy exchange processes across the air-sea interface in the light-wind MABL. Until now, very little turbulent flux data existed for a light-wind MABL. N3R has simultaneously acquired atmospheric turbulence and ocean surface data under a variety of stability regimes in a light-wind MABL. These data will be used to improve parameterizations describing air-sea transfer processes.

## **TRANSITIONS**

N3R data will be used by other CBLAST-Low investigators for surface-based and satellite-based intercomparisons. These data will support the test and refinement of parameterizations used in air-sea models. In addition, such measurements provide important boundary conditions to determine boundary layer turbulence and other atmospheric processes controlling the exchange of energy across the air-sea interface.

## **RELATED PROJECTS**

Data acquired by N3R in light wind regimes during the Wave Profile Experiment (WAPEx) and the Shoaling Waves Experiment (SHOWEX) are being used to augment data acquired in CBLAST-Low.

## **PUBLICATIONS**

Crescenti, G. H., J. R. French, and T. L. Crawford, 2001: Aircraft measurements in the Coupled Boundary Layers Air-Sea Transfer (CBLAST) light wind pilot field study. NOAA Technical Memorandum OAR ARL-241, Silver Spring, MD, 82 pp.

Crescenti, G. H., J. R. French, T. L. Crawford, and D. C. Vandemark, 2002: An integrated airborne measurement system for the determination of atmospheric turbulence and ocean surface wave field properties. Preprint, *Sixth Symposium on Integrated Observing Systems*, Orlando, FL, Jan. 13-17, Amer. Meteor. Soc., 60-67.